Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries

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Abstract Recycling water is an important aspect of water resource and environment management policies, ensuring reliable alternative water resources, reducing environmental pollution and achieving a more sustainable form of development. This paper focuses on wastewater reuse as a strategy for integrated water management. Key economic, financial, regulatory, social and technical factors that help to make water reuse projects successful are reviewed. Selected examples from Northern and Western Europe and arid and semi-arid Mediterranean regions illustrate the contribution of wastewater reuse to integrated management of water resources.

Keywords Wastewater reuse; integrated resource management; public acceptance; regulations; economic aspects

Introduction

Fresh water resources are becoming scarce in many countries, as a result of population growth, increasing pollution, poor water management practices, and climatic variations. Despite increasingly efficient water use in many developed countries, the demand for fresh water has continued to climb as the world's population and economic activity have expanded. According to some recent projections, in 2025 two thirds of the world's population will be suffering moderate to high water stress and about half of the population will face real constraints in their water supply. The situation is particularly critical in the Middle East and North Africa. Almost all conventional water resources have already been exploited in Saudi Arabia, the Arab Emirates, Oman, Qatar, Kuwait, Bahrain, Yemen, Jordan, Israel, Palestinian Territories and Libya; they are expected to be fully exploited in several other countries within the next few years.

The water crisis has also affected some temperate regions with normally plentiful resources, such as Europe and North America, where periods of drought are becoming more frequent and are lasting longer. Many parts of France, Italy, Spain and the UK have suffered successive droughts over the last few years, with the result that some watercourses have dried up and the level of groundwater supplies has reached a critical point.

One approach used to evaluate water scarcity is the exploitation rate of water resources (the ratio between the volume of available renewable water resources and annual withdrawals). When the exploitation rate exceeds 20% of existing reserves, water management becomes a vital element in country's economy.

In the Mediterranean region (Figure 1), this is currently the case in Egypt (last estimation 1968%, compared to 97% in 1997, data not shown), Jordan, Israel, Tunisia, Morocco,

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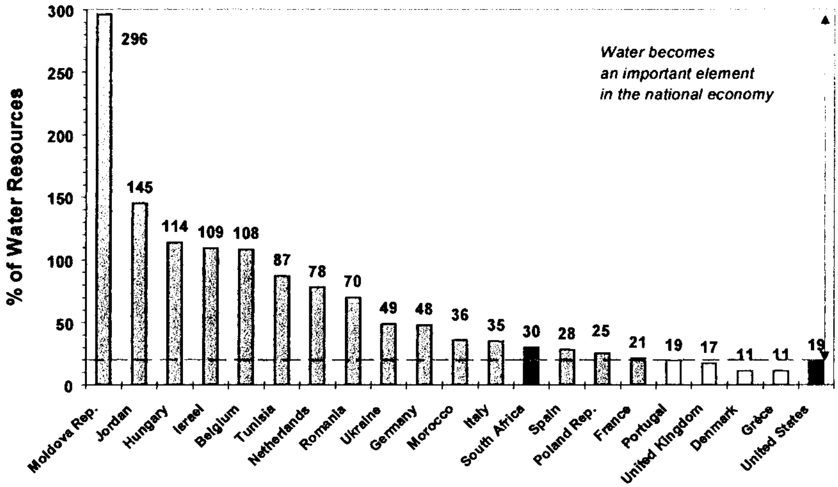

Figure 1 Renewable water resource exploitation rates in some European and Mediterranean countries, in comparison with the USA and South Africa

Italy and Spain (145 to 28%) (World Resources 1997–98). In Europe, it is the case in Belgium, the Netherlands, Germany, and France (108 to 21%), as well as some countries wishing to join the EU, such as Moldova, Hungary, Romania, Ukraine and Poland (296 to 25%). Moreover, numerous regions and islands in Europe, especially in Bulgaria, Greece, France, Portugal and the UK, have already reached an exploitation rate of almost 100% of their local water resources. These data suggest that to meet future needs, many countries will have to manage water resources far more efficiently than they do now.

Various strategies have been developed over the years in response to growing water demand, such as building infrastructures to transport water to deficient areas. Because such projects require much time and money, alternative solutions are being proposed, such as desalinating seawater or brackish water, water reuse and water conservation measures using water-efficient technologies such as drip irrigation and low-volume flush systems. In discussing alternatives, it is important to examine not only technical solutions but also socio-economic issues such as willingness to pay, public perceptions, risk analysis, assessment of monetary and non monetary benefits, as well as the environmental impacts. The water reuse option is often not only the most cost-effective solution, but it has the advantage of valorising the social and environmental value of water, enhancing a region's resource availability and minimising wastewater outflow with additional environmental benefits.

Integrated management of water resources: role of water reuse

The development and implementation of wastewater reuse practices around the world have shown that reclaimed water is a proven, reliable alternative resource, which can be sold as a new product: *recycled water*. More importantly, water reuse can bring in a whole new, holistic approach to water management: *integrated resource management with water reuse*, including wastewater management. This approach addresses both ends of the process: water demand and supply, and wastewater disposal and environmental protection. These two aspects of water management are regarded as complementary, interacting strands for progress towards more sustainable development. The notion of sustainable development encompasses several requirements including economic development on the basis of existing natural resources, but without damage to the natural environment.

It is an approach that favours the creation of closed, decentralised loops using alternative solutions suited to local constraints, and responding to present and future needs. Reusing wastewater with the use of appropriate treatment technologies shortens the natural water cycle.

To develop an integrated water management strategy in countries where water is short one must analyse all aspects of the following alternative solutions: (1) developing any undeveloped water resource, including desalination of brackish or sea water, (2) wastewater treatment and reuse, (3) inter-basin transfer, (4) more efficient irrigation systems, (5) minimising water leakage, (6) application of adequate charges for water, and (7) importing water from neighbouring countries. Improving the efficiency of water use and reducing waste and losses in distribution systems are the most affordable ways to address the problem of water scarcity; but pricing reforms, improved wastewater treatment technologies and wastewater reuse are becoming essential.

For almost all arid and semi-arid regions in the Mediterranean countries, where current fresh water reserves are at a critical limit, recycled wastewater is already the only affordable alternative resource for agricultural, industrial and urban non-potable purposes. In Israel and Tunisia, two countries which have adopted a firm national water reuse policy, reclaimed water is expected to satisfy 25% and 10% of total water demand respectively within the next few years. In Jordan, the volume of reclaimed water will have to increase by more then 400% by the year 2010. In Spain, more than 100 planned reuse schemes are in operation, mainly devoted to irrigation on farms, golf courses and parkland. Egypt is expected to increase the volume of recycled water it produces more than ten-fold by the year 2025. Finally, water reuse is likely to develop rapidly along the Mediterranean coast and, more especially, on Mediterranean islands.

Nevertheless, high investments must be put into the sewerage network when wastewater reuse is to be implemented. But given that wastewater collection and treatment is essential for protecting public health and preventing environmental pollution in countries with dense populations, the additional cost of wastewater reuse for irrigation, for example, represents only about 30% of the total cost of wastewater treatment and disposal.

Two major types of reuse have been developed and practised around the world: (1) potable uses, which can be direct, after high levels of treatment, or indirect, after passing through the natural environment and (2) direct or indirect non-potable uses in agriculture (irrigation), industry and urban settlements. Hitherto, the integration of wastewater reuse into existing water management master plans has been essentially geared towards agricultural irrigation. In southern Europe and the Mediterranean region, most such projects are designed to compensate for local and occasional water deficiencies, and to preserve the quality of the environment. Golf course irrigation is the fastest-growing reuse application in Europe, because of its high rate of water consumption and the increasing acreage concerned. Examples are to be found in Egypt (El-Gohary *et al.*, 1989), Tunisia (Bahri and Brissaud, 1995) and Morocco (Benchekroun and Bouchama, 1991). Urban non-potable reuse (irrigation of green areas, waterfalls, fountains, road cleaning, car wash, toilet flushing and fire fighting) is developing rapidly and is becoming a key element in integrated water management policies in high-density urban areas in the United States, Japan and the UAE. Indirect potable water production from wastewater is carried out on a large scale in the United States and becomes an important issue in Europe. The only existing example of direct potable water production is the Windhoek plant in Namibia: 25% recycled water, diluted with natural resource water. No negative impact of this type of water on human health has ever been reported. Aquifer recharge for indirect potable reuse is considered one of the most promising avenues for augmenting water supply with treated wastewater in dry regions, especially if advanced reclamation treatments become cheaper.

Key factors for the successful development of wastewater reuse

The keys to the success or failure of a water reuse project are economic, financial, regulatory, social and technical factors.

Technical challenges of water reuse

With available technologies, any water quality required by users and for compliance with existing regulations can be achieved. Extensive or intensive technologies can been applied, depending on local conditions, intended use of the water, plant size and water quality standards (Lazarova *et al*., 1998). However, costs may vary widely, making the choice of the most appropriate technologies a sensitive decision. In a number of Mediterranean countries, the choice of treatment technologies will be determined by the ease of maintenance, reliable operation and low O&M costs of reclamation plants.

The efficiency of a reuse project is improved by proper planning and by integrating water reuse in water management master plans. A number of reuse projects have been hampered or rendered impossible by the failure to plan wastewater treatment, disposal and reuse together in a coherent way. Administrative reorganisation may be necessary, but will not be enough in itself to avoid such disappointing situations.

Optimising integrated water management and planning requires new tools: integrated technical-economic models and decision making tools. These can greatly facilitate working out and comparing different water management scenarios, e.g. technical-economic evaluation and comparing wastewater reuse options with other alternatives (Xu *et al*., 2000).

One of the main technical challenges to water reuse systems is how to achieve a high level of operational reliability, not only of treatment facilities but also of storage reservoirs and distribution networks. Water quality control should be enhanced by the use of rational monitoring programs and new analytical tools. Defining and applying "best reuse practices" could also improve public health and safety.

Public acceptance

To develop sustainable water recycling schemes, an understanding of the social and cultural aspects of water reuse is required. Reuse projects can fail for lack of social support, and reuse for potable purposes meets with the strongest opposition, even in developed countries. Even for non-potable reuse purposes, public attitudes such as perception of water quality and willingness to pay or to accept a wastewater reuse project play an important part. In every country, the public's knowledge and understanding of the safety and applicability of recycled water is a key factor for the success of any water reuse programme.

As well as public perceptions of risk or acceptability, the problem of local capacities to utilise the technology is crucial. To achieve a better understanding of this range of socio-economic factors which dictate the success or failure of technology transfer from the research lab to the facility, the concept of "receptivity" is useful (Seaton *et al*., 1998). Receptivity can be defined as the extent to which there exists not only a willingness (or disposition) but also an ability (or capability) in different constituencies (individuals, communities, organisations, agencies etc.) to absorb, accept and utilise a given technology. Attitude and perception surveys and other social survey techniques recognise the fact that people think about products, services and other issues in different terms to the technologists, policy makers, planners or suppliers.

Standards and regulations

In most countries, setting up or adopting a regulatory framework is an essential step for the development and social acceptance of wastewater reuse. Decision makers and politicians

need clear, sound, reliable standards to endorse reuse projects. Regulations based on internationally acknowledged guidelines are generally preferred. Although an international effort to reduce discrepancies between current standards is highly desirable, regulations must be adapted to suit each individual country's context, health risk and affordability. Regulations have a major influence on the choice of treatment technologies and hence on the cost of reclaimed water reuse projects.

Existing water reuse standards can be divided into three categories according to origin: WHO, California and others. WHO-related regulations rely mainly on the document *Health guidelines for the use of wastewater in agriculture and aquaculture*, issued in 1989. Regulations in the USA are State-specific, but the main ones are the California Title 22 criteria (1978) and EPA 1992 recommendations. Other countries (Australia, South Africa) took the decision to develop their own standards. The most common parameters used in current regulations are microbiological (Table 1). At present, attention is paid only to some faecal indicators such as total and faecal coliforms (TC and FC) and helminths. Other pathogens such as viruses and protozoa are seldom determined and are rarely required as control criteria. Comprehensive wastewater reuse criteria must be developed to respond to the recent rapid expansion of this field. These new criteria require new analytical tools to be developed (e.g. for viruses and parasites), and corresponding planning and management measures to be introduced; these can be associated with treatment strategies, prevention plans, or public information requirements. The current criteria are closer to the reality of the risk. It is important to stress that without the appropriate analytical tools, the more stringent approach may be unrealistic.

Economic and financial analysis

Economic calculations focus on the level of investment needed to build and operate the reuse project, calculated on the basis of actual prices. Only the marginal cost of wastewater recycling (additional treatment, storage and distribution) must be considered, excluding the cost of wastewater collection and treatment. The distribution of capital and O&M costs depends on the types of treatment process applied. These costs are also strongly affected by

Table 1 Types of waterborne pathogens and indicators used in water reuse standards for irrigation

Parameter	Indicators	Existing stringent standards for irrigation	Observations
Bacteria	Faecal coliforms (FC), Total coliforms (TC), *Streptococcus faecalis, E coli,*	WHO: 1000 FC/100 mL Florida/Arizona/Israel: 2.2FC/100 mL Title 22, California: <2.2 TC/100 mL	FC determination is the more usual; *E. coli* determination is slowly replacing it
Viruses	Each virus (no indicator) – Hepatitis virus, Bacteriophage	Arizona/Hawaii: Enteroviruses <1pfu/40 L	There is still no accepted indicator
Helminths – Nematode	Nematode eggs (*Ascaris, Trichuris, Ancylostoma*)	WHO: < 1 helminth egg/1 L	Discouraging: a lot of negative results in many countries
Other helminths – (i.e. *Taenia*)	Not known		In some cases important (animal health hazard)
Protozoa – (*Giardia, Cryptosporidium, Amoeba, Balantidium*)	Not known (the presence of one could indicate the presence of the other)	Monitoring recommended in some countries during the first 2 years of operation (California, USA)	Analytical tools not well developed so far
Physico-chemical parameters	Turbidity (NTU), Total suspended solids, TSS	Arizona: < 1 NTU California: < 2 NTU Florida: <5 TSS/L	Easy on-line monitoring

local constraints: price of building land, distance between production site and consumers, need to install a dual distribution system or retrofitting. In many projects, the main capital investment is for the distribution system, which can amount to over 70 to 200% of overall cost, depending on the specific conditions of the site. New systems involve less expense than retrofitting existing networks. The financial analysis determines how the project can be financed, and whether operating revenues can cover operating and debt service costs. Most water reuse projects have been helped by subsidies and grants; few projects recover costs in full. Three pricing strategies often encountered (Young, 1996) where water resources management is combined with wastewater reclamation, recycling and reuse: (1) market prices may be applied; (2) where no market price exists, surrogate market prices are identified; (3) market prices or surrogate prices are not meaningful; in such cases the prices applied are called shadow prices (or sometimes accounting prices).

A water reuse project generates both monetary and non-monetary benefits. As a result, water reuse projects are often undervalued in comparison to other projects; significant opportunities for beneficial reuse are lost in this way (Sheikh *et al*., 1998). The non-monetary benefits are improved environmental quality and public health, reduced discharge of nutrients into receiving water, lower drinking water treatment costs, conservation of recreational land use and tourism. The typical benefits for the wastewater agency and local authorities include (1) reduced effluent discharge and preservation of discharge capacity, (2) elimination of some treatment processes to meet mass limits, i.e. for nutrients, (3) reduction or elimination of major sewers owing to construction of satellite water reclamation plants, and (4) sale of recycled water.

Integrated water management with water reuse: main scenarios

Europe (temperate climates)

In Europe, the development of water reuse is being driven by the need for alternative resources together, in most cases, with the need to protect receiving water bodies and increasingly stringent quality rules for discharged wastewater. Water reuse is growing steadily in densely populated Northern European countries like Belgium, England and Germany, and more rapidly in tourist coastal areas and on islands in Western and Southern Europe. There are many good examples of integrated resource management with water reuse on islands off France (Noirmoutier, Porquerolles), Spain (Balearic and Canary islands) and Italy (Sardinia, Sicily).

Despite its temperate, humid sea climate, Belgium is a European country experiencing water shortage (overextraction of groundwater) and using almost 100% of its renewable water resources. Water reuse is not only favoured by the existing legislation, but is also estimated to be a cost-effective solution for industrial and indirect potable purposes (Thoeye *et al*., 2000). In Wulpen WWTP, over 2.5 million m^3/year of urban effluent will be treated by microfiltration (MF) and reverse osmosis (RO), stored for 1–2 months in the aquifer and used for water supply augmentation. Another project, under investigation in Heist, will evaluate both MF/RO and MBR technology, to treat 10,000–24,000 m^3/d and recharge the aquifer.

Southeast England is another dry region in Europe, the driest part of the UK. Demand for water is increasing as more people move into the area, which is not far from Greater London. At the same time, droughts have been more frequent and the amount of water available to meet demand is declining. Water planners have had to develop schemes to close the gap between water supply and demand without extracting more water than the environment can bear. In addition to transferring river water from the northern part of the island, in 1994 the National Rivers Authority recognised the importance of recycling wastewater effluent, and this theory was applied specifically to augmenting flow in the River Chelmer and the volume stored in the Hanningfield reservoir in Essex. The result of

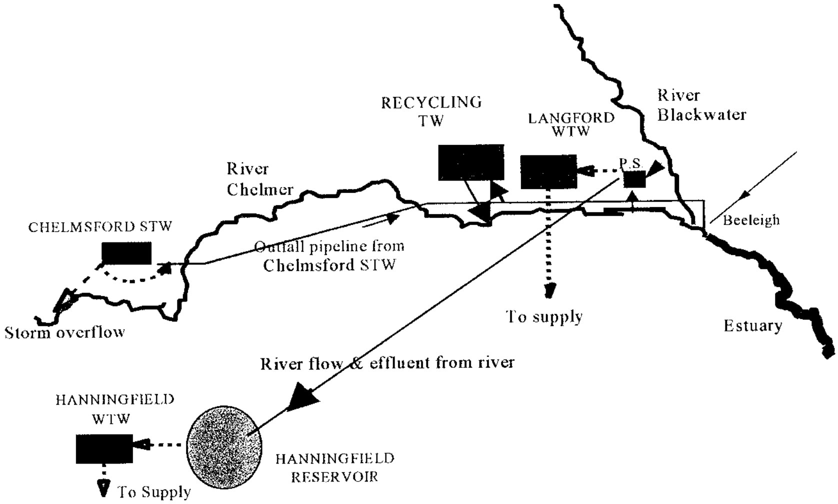

Figure 2 Chelmer augmentation scheme

this decision was the first indirect potable reuse project in Europe, the *Chelmer Augmentation Wastewater Reuse Scheme,* implemented in 1997 by the private company Essex & Suffolk Water (Figure 2). Strict water quality control has been introduced, including monitoring for viruses and oestrogens, and there have been numerous impact studies on the estuary ecosystem and public health.

Mediterranean region (arid and semi-arid climate)

Imbalance between water resources and needs is the main reason for the impressive advance of wastewater reuse in Israel. In 1994, wastewater reuse represented 20% of Israel's total water supply. Israel's objective is to treat and reuse most of its wastewater by 2010, which should represent 400 Mm^3 per year. This additional resource will be used for irrigating crops and animal fodder, under permits issued by the Ministry of Health (Gabbay, 1994). The Israeli government has estimated the cost of wastewater reuse at between 0.16 and 0.42 US$/$m^3$ (Shelef, 1991), a figure that includes the costs of treating, storing and conveying the wastewater.The two largest wastewater reuse schemes in Israel were developed many years ago. (1) The Dan Region project is the largest scheme of integrated water management in the country, and in the region. The secondary effluent from 1.5 million inhabitants of Greater Tel Aviv (95 Mm^3/year) goes to recharge the coastal aquifer for further treatment and storage. The recycled effluent, after a two-month transit and purification within the aquifer, is pumped and conveyed over 100 km for use in irrigation. (2) The Kishon Complex consists of two deep stabilisation reservoirs and a lake for seasonal storage of the secondary effluent of Haifa (32 Mm^3/year).

Tunisia is another Mediterranean country that has been developing planned reuse since the 1960s. Wastewater reuse has become a priority in the national water resource strategy. More than 44 WWTPs, with a total design capacity of over 130 Mm^3/year, produce secondary treated water, of which about 30% is recycled, most of it being used to irrigate some 6,500 ha of farmland. Many other projects are planned and the total area irrigated with recycled water will be extended to 30,000 ha over the next few years. The largest existing reuse project is around Tunis and along the Mediterranean coast; the treated water is used to irrigate industrial, fodder and tree crops, cereals and golf courses (Bahri, 1998). An institutional and legal framework has been set up to organise the treatment, distribution and quality control of recycled water.

"Zero discharge" scenarios

In Europe, the first "zero discharge" systems have appeared in coastal areas and on islands, on a relatively small scale. One example is the island of Mont Saint Michel (France). Recently however, numerous municipalities have begun to consider this solution when developing water management master plans. On Noirmoutier island (France) for example, reclaimed wastewater will account for up to 100% of agricultural irrigation demand (350,000 m^3/year). On Noirmoutier, water reuse will not only increase available water resources, which are at present imported from the continent, but also prevent contamination of sensitive coastal areas. Technical-economic assessments of various water management scenarios have shown that wastewater reuse for agricultural and landscape irrigation is the most attractive and cost-efficient way to solve the water scarcity problem and improve the quality of the island's fragile environment. Indirect potable reuse and desalination cost more than imported water, and should be regarded as long term alternatives (Xu *et al*., 2000).

On a larger scale, the city of St. Petersburg in Florida (USA), with a population of 250,000 inhabitants, has developed one of the largest looped dual distribution systems in the world to recycle wastewater and to achieve "zero discharge" of wastewater to the surrounding Tampa and Boca Ciega Bays. The system supplies domestic, commercial and industrial users (Johnson and Parnell, 1998). The main factors driving water reuse development have been: (1) increasing demand for freshwater and lack of water resources, decreasing run-off and repeated droughts; (2) stringent standards for wastewater treatment and disposal to avoid pollution of coastal areas; and (3) local specificities, including intrusion of seawater into the aquifer.

This significant progress was gradually achieved over a 15-year period, using state and governmental grants; it is an excellent example of the planning and implementation of new water and wastewater management solutions. An advanced, decentralised treatment system has been adopted for the programme: advanced secondary treatment, filtration and chlorination to ensure a turbidity of 2 NTU for 24h and an average faecal coliform concentration of 2.2 FC/100 mL. This way, pipe diameters have been reduced and a large looped distribution system constructed, interconnecting four treatment plants with a total capacity of about 260,000 m^3/d. The recycled water is stored in a system of covered reservoirs, covering one day's irrigation demand (92,000 m^3). To maintain zero-discharge to surface water at each treatment plant, deep-well injection systems have been constructed for alternative effluent disposal.

Conclusions

An imbalance between water resources and demand and increasing pollution make comprehensive integrated water management a necessity. Water recycling has a vital part to play in this: recycled water has been proven to be a reliable alternative resource and wastewater reuse prevents degradation of receiving water bodies and the environment. Water reuse projects have been successful not only in arid and semi-arid regions but also in regions with temperate climate, to protect sensitive areas, recreational activities and water-intensive economic sectors, and to cope with water crises caused by repeated droughts. In several Mediterranean countries, recycled wastewater is the only significant low-cost alternative resource for irrigation.

A proactive approach has to be developed to ensure the sustainable management of all resources, recognising that water is a precious, finite and irreplaceable resource. Efforts must be made to develop efficient and comprehensive planning tools; integrated water management models should be of great assistance. Our understanding of public perceptions and attitudes towards water recycling has to be improved; this will be all the more impor-

tant as potable recycling is likely to be introduced in the near future. Consistent, if not uniform, international regulations will have to be set up for the Euro-Mediterranean region. More attention must be paid to careful financial planning and to proper economic analysis that takes all the benefits of water reuse into account.

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